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COMPACTED FLY ASH WITH ADDITIVES: A POTENTIAL CONSTRUCTION MATERIAL FOR HYDRAULIC BARRIERS

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ABSTRACT

In the design of a solid waste landfill mound, a final cover and a liner (hydraulic barriers) are usually incorporated to meet stringent government environmental requirements. Limited published data have indicated that compacted fly ash with lime or bentonite mixes can be quite impermeable. These mixed materials may, therefore, be used in lieu of natural clays for the construction of the hydraulic barriers.

To investigate the feasibility of using Ontario's fly ash for this potentially large-volume utilization option, a laboratory study was undertaken on the hydraulic properties of specimens prepared by compacting mixtures of fly ash and various additives, such as calcium bentonite; sodium bentonite; lime kiln dust, a waste by-product from a lime manufacturing plant; and other candidates. To date, laboratory test results have indicated that, of various trial mixes, fly ash mixed with calcium bentonite and lime dust is the most promising construction material for hydraulic barriers.

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TABLE OF CONTENTS

		PAGE
1.0	INTRODUCTION	1
2.0	LABORATORY PROGRAM	2
2.1	Candidate Additives	2
2.2	Fly Ash	4
2.3	Preparation of Specimens	4
2.4	Hydraulic Conductivity	5
3.0	DISCUSSION	6
4.0	SUMMARY	7
ACKNOWLEDGEMENTS		8
REFERENCES		9
TABLE 1 TO 2		10
FIGURE 1 TO 3		12
DISTRIBUTION		last page

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COMPACTED FLY ASH WITH ADDITIVES: A POTENTIAL CONSTRUCTION MATERIAL FOR HYDRAULIC BARRIERS

1.0 INTRODUCTION

Each year, many millions of tonnes of municipal solid wastes (MSWs) are disposed of by means of landfilling in Canada and other parts of the world. In 1979, the estimated number of MSW landfills in North America was about 20 000/1/. At present, the estimated number exceeds 30 000. To minimize the impact of the MSW leachate from a sanitary landfill on the quality of the groundwater beneath and adjacent to the landfill, hydraulic barriers (a cover and a liner) to contain the waste are usually incorporated into the construction (Figure 1). Owing to its imperviousness, a hydraulic barrier can function as a permanent cover layer on the solid waste landfill or as a liner beneath it. A well constructed cover can substantially reduce the amount of surface water infiltrating the waste. A liner can greatly slow down the rate of leachate percolating into the groundwater system. Depending on the liner material, a liner may also serve to retard the movement of contaminants in the leachate.

Landfill covers and liners are frequently constructed of natural soils or synthetic membranes. Natural materials such as well compacted clays are excellent because of their imperviousness and their ability to retard contaminants. A compacted soil cover should have a hydraulic conductivity value of 10^{-9} m/s or less/2/. Each year, millions of cubic metres of natural soils are used in thousands of MSW landfills as liner or cover construction materials. For example, over a seven year period (1983 to 1990), approximately 1.2 million cubic metres of clay liner material excavated at a significant cost

was placed at a landfill site near Toronto/3/. This depletion of natural resources should be avoided if alternative construction materials can be used.

At Ontario Hydro's three coal-fired generating stations (Lakeview, Nanticoke, and Lambton) located in Southern Ontario, approximately 0.8 million tonnes of class "F" bituminous fly ash are produced annually. About 25% of the ash is used in various engineering applications and in the production of building materials/4/. Despite some success in fly ash utilization in the past 30 years, Ontario Hydro is continuing its efforts to search for new or innovative fly ash utilization options. Recently, the potential use of fly ash as a construction material for hydraulic barriers for the containment of solid waste landfills has been identified. As explained previously, such an application would use large volumes of fly ash.

2.0 LABORATORY PROGRAM

A laboratory testing program was initiated in 1990 to measure the hydraulic conductivity (k) of specimens prepared by compacting mixtures of fly ash and selected additives. The main objective was to identify specimens with optimum proportions of fly ash to additive(s), yielding a hydraulic conductivity value of 10^{-9}m/ or less.

2.1 Candidate Additives

The selection of additives was based on three factors: (1) past performance of the material as indicated by published data, (2) cost of the material, and (3) availability of the material.

The selected candidates and some of their characteristics were:

(1) Sodium bentonite
- natural soil
- product of chemical alteration of volcanic ash
- composed of about 80% montmorillonite and 20% other minerals
- "high-swell" bentonite containing sodium montmorillonite
- commercially available
- cohesive

(2) Calcium bentonite
- smaller swelling capacity than the sodium type, therefore, physically more stable in the event of chemical changes of pore fluid
- commercially available
- cohesive

(3) "Red mud"
- crushed bauxite
- waste by-product from aluminum smelters
- available in large quantities
- cohesive

(4) Limestone screenings
- discarded materials from crushed limestone aggregates
- available from limestone quarries
- non-cohesive

(5) Lime kiln dust
- waste material from lime manufacturing plants
- some available free lime and, therefore, possessing self-cementing properties

(6) Clay from southern Ontario
- availability depends on locations
- containing mainly non-swelling illite type minerals
- cohesive

Figure 2 shows the particle size distribution curves and Table 1 lists the chemical composition of these additives.

The imperviousness of bentonite is well documented but cost is in the range of $50 to $100 (Canadian currency) per tonne depending on the source of the material. The quantity required would make it a relatively expensive additive to use. The candidate waste by-products (e.g. lime dust) are freely available, the main cost being for transportation. The cost for an Ontario clay, including the expense for excavation, handling, and transportation, should be less than the cost of bentonite.

2.2 Fly Ash

The fly ash that was used to mix with the candidate additives was obtained from Ontario Hydro's Lakeview coal-fired station near Toronto, Ontario. The fly ash was a type "F" bituminous ash with little self-cementing property and consisted of mainly silt-sized particles as illustrated in Figure 2. The chemical composition of this fly ash is given in Table 1. According to the data obtained by Ontario Hydro, the hydraulic conductivity of the compacted fly ash is 10^{-7} m/s or greater.

2.3 Preparation of Specimens

Because the main objective of the study was to promote fly ash utilization, the highest feasible percentage of fly ash was used in mixing with a selected additive. The cost of the additives was also considered. The percentage of additive in a mix was kept between 10% and 30%.

The components used in preparing the mixes were oven-dried and the amounts (by weight) of the individual materials were pre-determined. The materials were first mixed in a dry state in a mixing bowl, then a known amount of tap water was added. The thoroughly mixed material in a moist state was used for preparing a test specimen.

As a guide in choosing the amount of mixing water and the bulk density of a compacted specimen for the hydraulic conductivity test, standard Proctor compaction tests were initially performed on various trial mixes. The compaction data are illustrated in Figure 3. The maximum density for a certain mixed material depends on the amount of compactive energy applied and for a standard Proctor test, the compactive energy is standardized. With conventional field compaction equipment, it would not be too difficult to achieve the maximum or 95% of the maximum Proctor density at a construction site.

For hydraulic conductivity tests, the specimens were compacted to a density close to the maximum Proctor density. However, unlike the dynamic Proctor compaction test, the specimens were compacted by a press in a static manner in a steel mold 10 cm in diameter and 5 cm in height. The static compaction was expected to yield more uniformly compacted specimens.

2.4 Hydraulic Conductivity

Laboratory hydraulic conductivity measurements on compacted candidate specimens were performed using the "constant-head" method/5/. That is, the hydraulic pressure applied to a specimen remained constant during the test. Knowing the cross-sectional area of the specimen and the applied hydraulic gradient, it was possible to calculate the hydraulic conductivity of the specimen, by measuring the flow rate through it. In this stage of the study, tap water was the permeant used for all the tests. A test was performed for a period of up to four weeks to get an appreciation of the effect of time on hydraulic conductivity.

The values of hydraulic conductivity for various specimens are summarized graphically in Table 2. For some specimens, the densities were chosen on the basis of the Proctor compaction results. For the remaining specimens, the Proctor compaction results were used only as a guide in deciding water content and density. The water content, expressed as a percentage of the dry weight of solids, was the measured water content of a specimen at the beginning of the hydraulic conductivity test.

Some comments and observations on the hydraulic conductivity (k) data are presented.

(1) In principle, the k value of a specimen should decrease with an increase in its dry density. This was not always the case as indicated by the hydraulic conductivity test results. The anomaly could be due to several factors, such as non-uniform mixing of the component materials, varying degrees of compaction within a specimen, existence of micro channels, etc.

(2) The fly ash specimen with 20% lime dust and 10% Ca bentonite yielded a k value less than the 10^{-9} m/s, recommended for hydraulic barriers. However, the reaction between the lime dust and Na bentonite appeared less favourable because these specimens rendered k values less than those of Ca bentonite mixes.

(3) The k values of fly ash specimens with 20 or 25% Na bentonite were less than 10^{-9} m/s. The Na bentonite with a greater swelling property was more effective than the Ca bentonite in reducing the hydraulic conductivity of the ash.

(4) The specimen with 30% lime dust yielded a k value of 2.1×10^{-9} m/s, close to the 10^{-9} m/s recommended value.

(5) Limestone screenings were not effective in increasing the imperviousness of a compacted fly ash. This could be due to a lack of fine-grained particles in this additive (see Figure 2). "Red mud" and clayey silt were also not effective, even though they were slightly better than limestone screenings. The particle sizes and the non-swelling clay minerals in these additives were the main contributing factors.

(6) The hydraulic conductivity test results from this study were similar to those obtained by Bowders on fly ash and bentonite mixes/6/. Two types of fly ash were used by Bowders and they showed significant differences in hydraulic conductivity.

3.0 DISCUSSION

The hydraulic conductivity of the specimens tested can be decreased in two ways:

(1) Increase the percentage of the additive in the mix. This option has limitations because, in order to promote large-volume ash use, it is more practical and economical to put as little additive as possible in the ash. In this project the percentage was limited to less than 30%.

(2) Increase the dry density of the compacted mixed material. Based on experience with natural silts and clays, an increase of 20% in the dry density would decrease the k value by one order of magnitude. For those specimens, e.g. fly ash and Ca bentonite, that yielded k values close to 10^{-9} m/s, a small increase in dry density could decrease the k values to 10^{-9} m/s or less.

Fly ash and bentonites (Na and Ca) can be used as a construction material for a land fill cover. The mixture is a semi-plastic material and,therefore,would be less susceptible to the effect of differential settlements of the solid waste landfill. The effect of seasonal water content changes in the cover material should not affect the hydraulic performance of the bentonite because of its swelling property.

The use of fly ash mixed with lime dust and Ca bentonite would be suitable as a construction material for a landfill liner. The more rigid nature of the material would provide good support for the overlying solid waste landfill. It is estimated that the leachate from the MSW landfill would not change the hydraulic performance of the mixed

material. This is based on the fact that fly ash and calcium bentonite are chemically similar to a natural clay and the lime dust is basically a partially calcined limestone. The study by Quigley /3/ on the compatibility of municipal solid waste leachate and a clay liner showed that the k values of the clay specimens were similar when water or the leachate were used as permeants.

4.0 SUMMARY

A laboratory testing program was carried out at Ontario Hydro to study the feasibility of using compacted fly ash mixed with certain additives as construction materials for landfill hydraulic barriers. Test results have shown that by using Na bentonite, or a mixture of lime dust and Ca bentonite, it was possible to achieve k values lower than 10^{-9} m/s, generally considered acceptable for the barriers. In principle, the leachate from a MSW landfill should not cause significant changes in the hydraulic conductivity of these modified fly ash materials. Leachate was not used in the present hydraulic conductivity tests. The minimal effect of the leachate on the hydraulic conductivity of the modified fly ash will be part of the additional experimental study being planned. Also, more hydraulic conductivity tests will be performed on specimens made up of mixtures of fly ash and Ca bentonite, or Na bentonite, or Ca bentonite and lime dust. The specimens will be compacted to a higher density than those used previously. The preference and emphasis is to try various waste materials, such as the lime dust, as candidate additives for economic reason.

It is our belief that the experimental results reported here, together with additional results from laboratory and field tests, will open a new avenue to a challenging large-volume fly ash utilization option.

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REFERENCES

1. R.A. Freeze and J.A. Cherry. Groundwater. Printice-Hall, 1979.

2. I.S. Owesis and R.P. Khera. Geotechnology of Waste Management. London: Butterworth 1990.

3. D.W. Readers, L.R. Lahti, R.M. Quigley, and A. Bacopoulos. Detailed Case History of Clay Liner Performance. In: Clay Barriers for Mitigation of Contaminant Impact: Evaluation and Design Vol. 2. Short Course Notes, May 7-8, 1990. London, Ontario: Faculty of Engineering Science, University of Western Ontario, 1990.

4. H.T. Chan. Coal Ash - A Resource Material. Ontario Hydro Research Division Report No. 89-288-K, 1989.

5. G.B. Sowers and G.F. Sowers. Introductory Soil Mechanics and Foundations. Third Edition London: The MacMillan Co., Collier-MacMillan 1970.

6. J.J. Bowders, Jr. Fly Ash Liners for Waste Disposal Facilities. Geotechnical News, pp. 26-29, December 1988.

TABLE 1

CHEMICAL COMPOSITION OF FLY ASH AND ADDITIVES

	Fly Ash	Lime Kiln Dust	"Red Mud"	Sodium Bentonite	Calcium Bentonite
SiO_2	42.3	0.8	14.8	65.0	59.5
Al_2O_3	23.2	0.1	20.4	20.2	16.7
Fe_2O_3	14.7	2.0	35.4	2.3	3.8
CaO	2.8	38.0*	3.1	1.4	1.4
Na_2O	0.7		7.8	3.1	0.6
K_2O	2.1		0.1	1.0	0.9
MgO	1.0	25.0*	0.1	1.0	4.0
SrO					
TiO_2			5.5		0.5
BaO					
P_2O_5	0.5		0.2		0.2
SO_3	0.9	2.0			
LOI	7.9	32.0**	9.5	7.0	21.7

* Total free lime ranges from 10-20%
** High LOI because the lime dust is not fully calcined.

TABLE 2

SUMMARY OF HYDRAULIC CONDUCTIVITY TEST DATA

ADDITIVES (% by weight)	DRY DENSITY (kg/m³)	WET DENSITY (kg/m³)	WATER CONTENT (%)	HYDRAULIC CONDUCTIVITY k (m/s)
LIME DUST (20%) *	1186	1620	36.5	1.2×10^{-8}
LIME DUST (20%)	1245	1699	36.5	4.3×10^{-9}
LIME DUST (25%)	1224	1623	32.6	1.4×10^{-8}
LIME DUST (25%)	1307	1733	32.6	3.2×10^{-8}
LIME DUST (30%)	1186	1620	36.5	2.1×10^{-9}
LIME DUST (30%)*	1200	1612	34.0	6.6×10^{-9}
Ca BENTONITE (10%)	1216	1662	36.6	6.5×10^{-9}
Ca BENTONITE (15%) *	1177	1613	36.6	2.2×10^{-8}
Ca BENTONITE (15%)	1211	1655	36.6	1.2×10^{-8}
Ca BENTONITE (15%)	1250	1707	36.6	6.6×10^{-9}
Ca BENTONITE (20%)	1177	1613	36.6	2.1×10^{-9}
Ca BENTONITE (25%)	1234	1687	36.6	5.8×10^{-9}
LIME DUST (10%) & Ca BENTONITE (10%)	1267	1674	33.0	4.2×10^{-9}
LIME DUST (20%) & Ca BENTONITE (10%) *	1267	1674	33.0	7.4×10^{-10}
LIME DUST (20%) & Ca BENTONITE (5%)	1267	1674	33.0	2.5×10^{-9}
Na BENTONITE (15%)	1177	1613	36.6	8.8×10^{-9}
Na BENTONITE (20%) *	1217	1644	33.3	5.3×10^{-10}
Na BENTONITE (25%)	1217	1644	33.3	9.4×10^{-10}
LIME DUST (20%) & Na BENTONITE (5%)	1267	1674	33.0	4.6×10^{-9}
LIME DUST (20%) & Na BENTONITE (10%)	1267	1674	33.0	6.3×10^{-9}
LIMESTONE SCREENINGS (20%) *	1262	1660	31.6	3.9×10^{-8}
LIMESTONE SCREENINGS (20%)	1324	1724	31.6	9.7×10^{-8}
LIMESTONE SCREENINGS (30%)	1262	1660	31.6	1.0×10^{-7}
RED MUD (20%)	1295	1554	20.0	6.0×10^{-8}
RED MUD (20%)	1355	1626	20.0	4.2×10^{-8}
RED MUD (25%) *	1217	1647	35.3	1.4×10^{-8}
CLAYEY SILT (10%)	1267	1674	33.0	1.8×10^{-8}
CLAYEY SILT (15%)	1267	1674	33.0	8.6×10^{-9}
CLAYEY SILT (10%) & LIME DUST (20%)	1267	1674	33.0	7.2×10^{-9}

* The densities and water contents used were derived from standard Proctor test results.

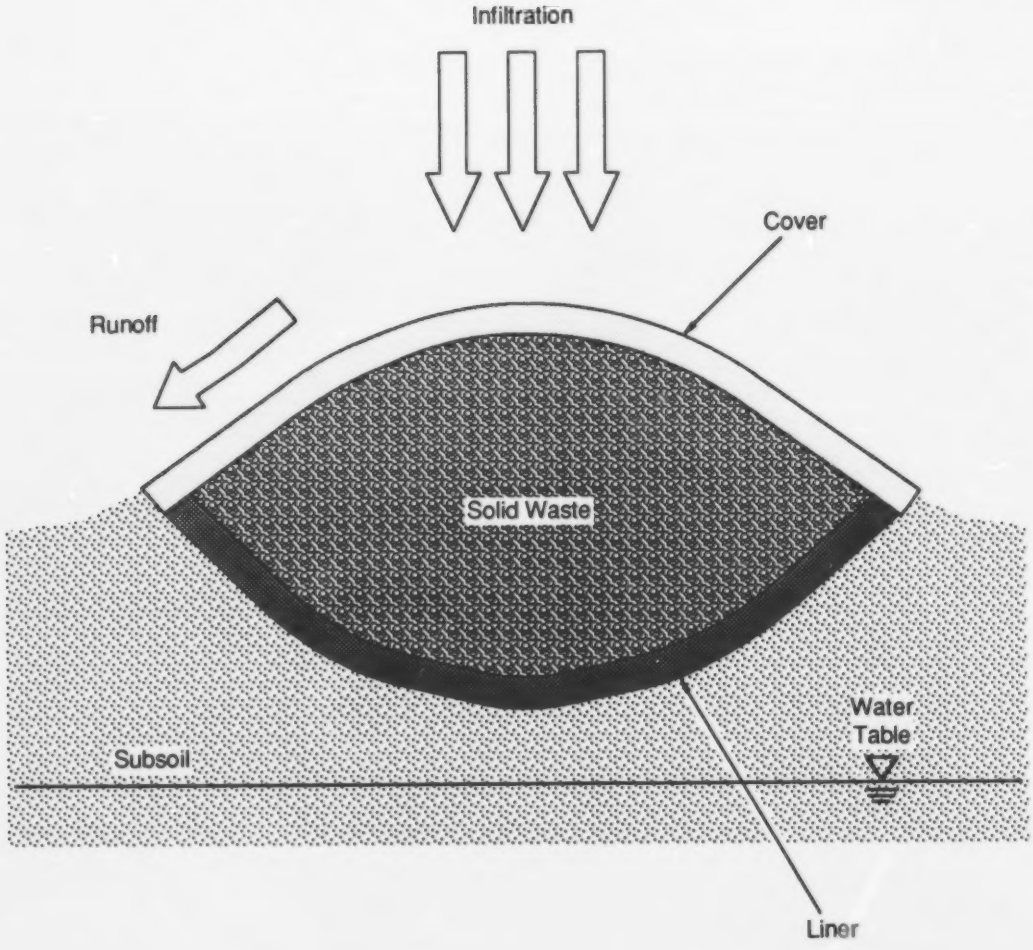

FIGURE 1

A SCHEMATIC DRAWING OF A SOLID WASTE LANDFILL WITH A COVER AND A LINER

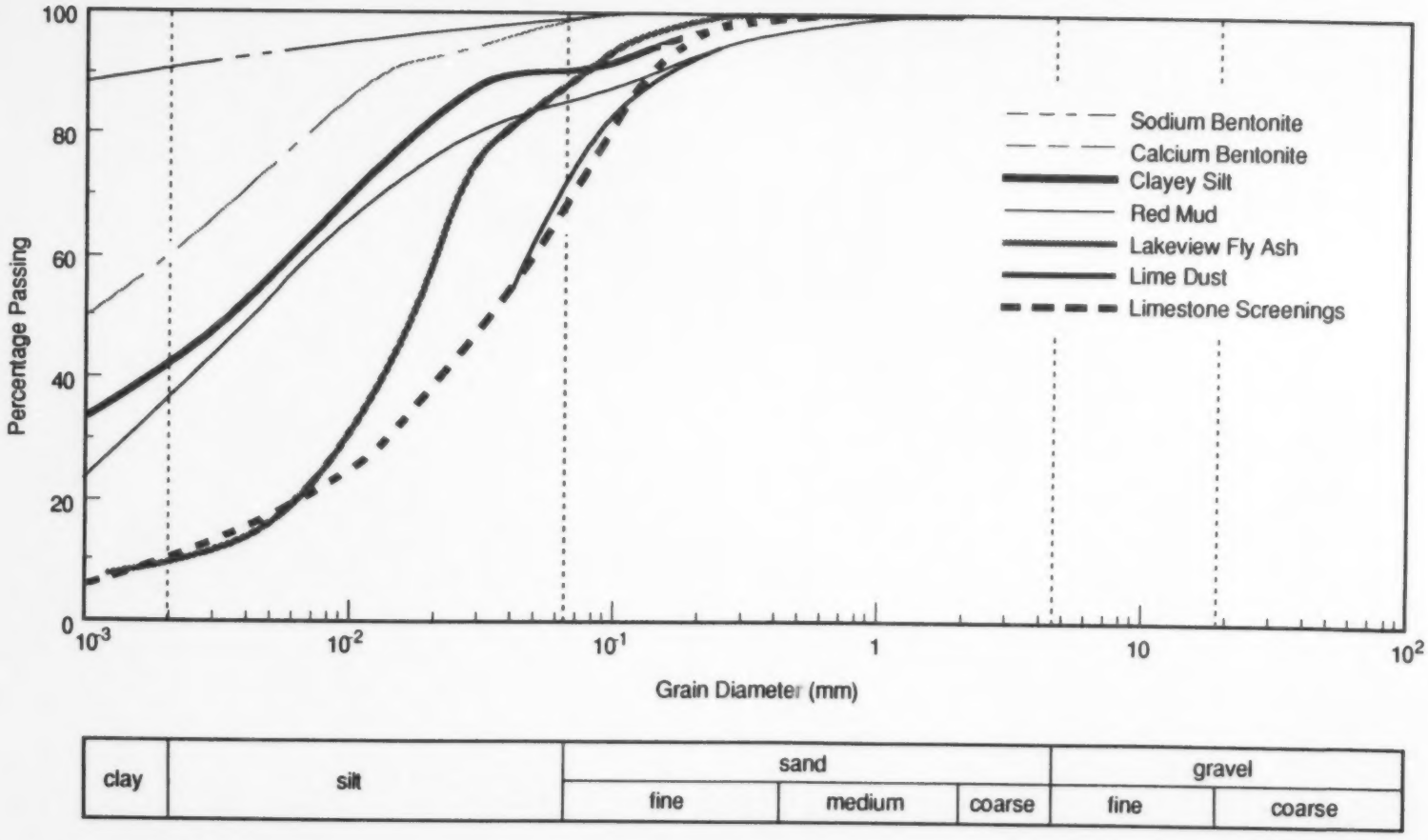

FIGURE 2

PARTICLE SIZE DISTRIBUTION CURVES OF FLY ASH AND ADDITIVES

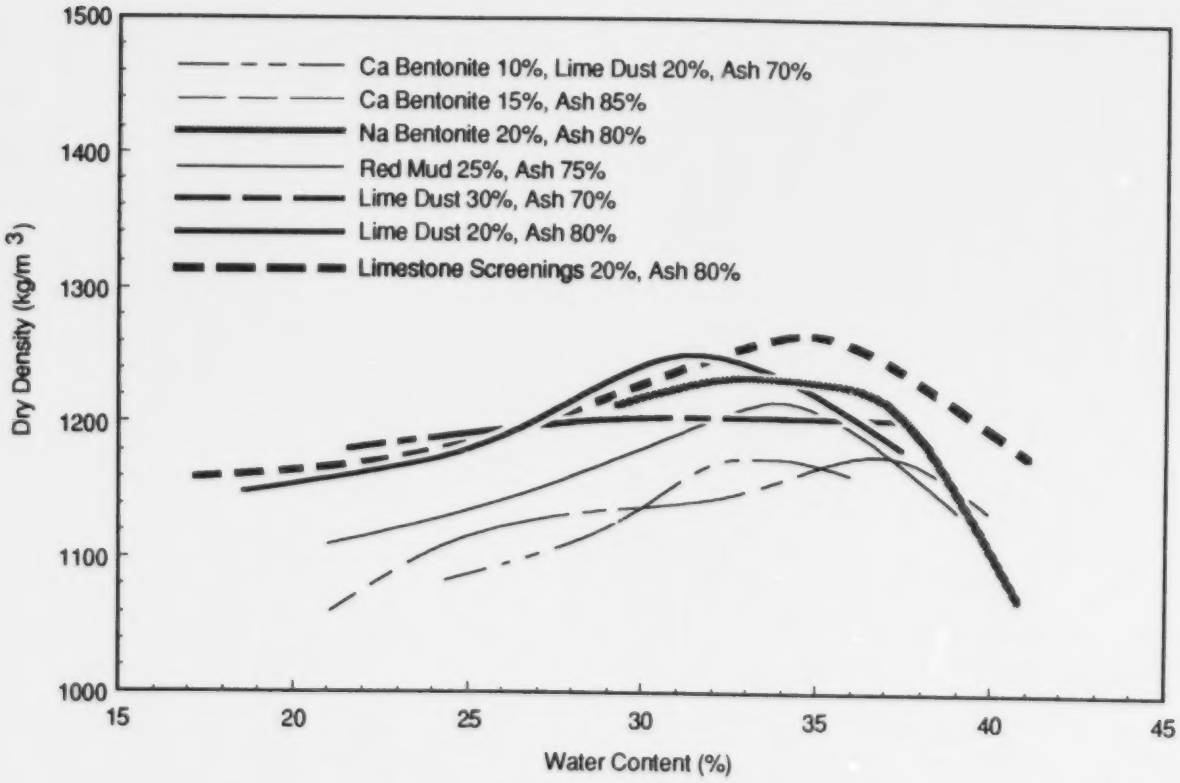

FIGURE 3

STANDARD PROCTOR COMPACTION CURVES OF VARIOUS MIXES OF FLY ASH AND ADDITIVES